Saskatchewan
Agriculture
and Food

ADF

AGRICULTURE DEVELOPMENT FUND

FINAL REPORT

20060059

MUSTARD 21 - LEADING CANADA'S MUSTARD INDUSTRY THROUGH THE 21ST CENTURY

Funded by: The Agriculture Development Fund

June 2008

Prepared by: Saskatchewan Mustard Development Commission

Mustard 21 Strategic Plan
Path Forward 2021

Table of Contents

Executive Summary 2
1. Introduction 4
1.1 Overview 4
1.2 Key Areas of Focus 6
2. Mustard Opportunity Assessment 8
2.1 Overview 8
2.2 Economic Results 10
3. Mustard Strategy for Opportunity Sectors 12
3.1 Biofuels and Fuel Additives 12
3.1.1 Renewable Fuels and Fuel Additives Product Overview 12
3.1.2 M21 Strategy for Renewable Fuels and Fuel Additives from Mustard 14
3.2 Biopesticide 14
3.2.1 Product Overview 14
3.2.2 M21 Strategy for Biopesticide from Mustard 16
3.3 Condiments and Spices 16
3.3.1 Condiment Product Overview 16
3.3.2 M21 Strategy for Mustard Condiment Market Development 17
3.4 Protein and Food Ingredients 17
3.4.1 Mustard Protein Isolates and Concentrates 17
3.4.2 Mustard as a Food Preservative 19
3.4.3 M21 Strategy for Mustard as a Source of Protein and Food Ingredients 19
3.5 Mucilage and Fibre Ingredients 20
3.5.1 Overview 20
3.5.2 M21 Strategy for Mucilage and Fibre Ingredients 20
3.6 Oleochemicals 21
3.6.1 Oleochemical Product Overview 21
3.6.2 M21 Strategy for Oleochemical Derived from Mustard 22
4. Mustard 21 Priorities 23
4.1 Priorities for Plant Breeding and Agronomy 23
4.2 Priorities for Processing and Gross Manufacturing 24
4.3 Priorities for Formulation and Product Development 24
4.4 Priorities for Market Access and Partnering 25
5. Mustard 21 Path Forward 25
6. Appendix 26

Executive Summary

Mustard 21 is an initiative aimed at creating a vibrant Canadian mustard industry and increasing its present value by four to five times through development of new products and applications. Mustard's primary usage today in North America and Europe is in the food industry. There are a multitude of opportunities for mustard beyond this traditional use.

Given the need to create early wins, the first phase of this analysis is focused on biofuel and biofuel additives, biopesticide, and an integrated mucilage plus protein opportunity.

Economic analysis suggests some of the alternatives explored, especially biofuel and biopesticide, could add as much as $2,100 - 3,000/tonne in revenue. These industrial mustard opportunities could create $100 - 150 million from just 100,000 acres of new production.

Mustard as biofuel

Biofuel is an important driver as it provides a new high-value opportunity for the oil. This opportunity is available immediately with Canada's 2 percent mandatory bio-diesel requirement by 2010. Given the M21 goal of driving a four to five times increase in revenue from mustard, this is an important distinction.

Relative to current and biofuel uses of canola, mustard has economic advantages. The advantage is primarily attributed to the high value uses of meal for biopesticide or protein. This is an important nuance as we observe increasing competition for farmland in areas where both mustard and canola can be grown. This distinction for mustard is useful as producers align with large crushers where identity preservation systems will be key.

In Western Canada, canola oil from *Brassica napus* could be augmented by *B. juncea* mustard as an immediate crop alternative available to growers for biodiesel production in semiarid areas of the prairies. Canola Council of Canada's projections for canola oil for food and fuel use suggest an opportunity of one to two million acres annually for *B. juncea* canola type mustard production. This represents a $450 – 900 million opportunity in crop production for *B. juncea* in the prairies either as canola or mustard type.

Mustard as biopesticide

The biopesticide market is expected grow with consumer interest in the use of natural products in preference to synthetic chemicals and as increasing numbers of conventional synthetic products are restricted in use or removed from the market. To be realized, this opportunity will require two to three years of focused commercialization efforts.

The present fumigant market potential in the USA in specialty, high-value crops and fruit markets is approximately eight million acres. There is also the additional, higher value professional turf and golf course market. It is a $400 and $600 million export

opportunity. This is a critical market opportunity to create high value for mustard meal. This market will need to be developed with a clear understanding of the business proposition and path to market entry.

Mustard in food

Mustard seed is an excellent source of soluble fibre, primarily found as mucilage and beta-glucan. Because of their viscous nature, mustard gums have potential applications as food and supplement ingredients for serum lipid lowering and blood glucose moderation. Due to these properties, there is interest in determining the effects of isolated mustard gums on the glycemic index (GI). This is a relatively near-term opportunity that needs close watch based on the GI data developed by University of Manitoba.

Global sales of protein ingredients are expected to increase to $18 billion by 2010. The plant protein ingredients market is the fastest growing segment with a projected annual growth rate of eight percent over the next five years. There appear to be opportunities to expand mustard protein usage in traditional foods and for various new processed food products aimed at the health and nutrition market. Protein is a long-term opportunity for mustard.

Delivering on value

To deliver on this potential, there is much that remains to be done. Mustard 21 and the mustard industry need to:

1. Align all resources to address mustard yield so the crop can compete with crops like durum, canola, lentils and flax in the drier prairies. ***Yield is the most significant factor that needs to be tackled to maintain the competitiveness of the mustard crop*** relative to other crops. Mustard yield has not kept up with the yield increases of other crops, especially canola, over the last fifteen years.

2. E***xplore opportunities and build partnerships throughout the value chain to enhance the contribution of mustard's unique characteristics*** in a biofuel, vegetable-oil based agriculture economy.

3. A***ssume leadership to champion the coordination and promotion*** of the opportunity for *B. juncea* as a natural biopesticide as one of its top priorities. Successful delivery of this potential will require large volumes of mustard seed and infrastructure. To realize this potential, M21 will need to assist in the completion of an in-depth analysis of the opportunity by defining the market potential and economic feasibility of the business.

4. ***Capitalize on and promote the culinary characteristics*** of traditional condiment mustard and increase consumer interest in products which are all natural, organic, low carbohydrate, lower fat and flavorful. Successful delivery of this objective will support the growth and development of the current mustard industry.

5. Undertaking and supporting ***competitive and economic analysis of competing protein sources, current processing and future technology requirements for yellow mustard protein*** will be critical to extract maximum value from mustard meal.

A change of oil profile and increase of oil is critical for some of these industrial applications like biofuels and biopesticide. SMDC and CMA should give ***strategic consideration to developing an "Industrial Mustard". This will protect the present condiment market and will allow the use of the latest technologies including genetic modification to help the breeding program***.

1. Introduction

This report summarizes the first phase of Mustard 21, an initiative to create a strong and vibrant Canadian mustard industry in the 21st century through the leadership of the grower-led Saskatchewan Mustard Development Commission (SMDC) and the Canadian Mustard Association (CMA). This initiative is intended to build a stronger partnership with the present value-added chain in the mustard industry.

The overall objective of the present Mustard 21 project is to create wealth in Canada by increasing the overall value of the mustard industry. This will be done by:

1. Increasing the value of the mustard seed industry in Canada to $500 million from the present $72 million through development of new products and applications;
2. Increasing domestic processing, extraction and use of mustard seed from approximately 13 percent of 240,000 hectares to 50 percent of 500,000 hectares of production;
3. Increasing the competitiveness of Canada's global position as mustard supplier;
4. Aligning production, agronomy and breeding to develop newer mustard cultivars that meet the requirements of the domestic value chain; and
5. Establishing an action plan with key stakeholders and industrial partners on future governance and obtaining commitment to implement the strategy after April 1, 2008.

Phase II of Mustard 21 will develop a business plan to implement the three strategic opportunities with key stakeholders, especially industrial partners, to create the economic activities identified in this phase.

1.1 Overview

At least 50 percent and as much as 80 percent of Canadian mustard is grown under contract each year. Identity preservation and traceability systems have been in place for many years. Measures are taken to segregate mustard from visually similar canola. Grower lot histories and samples are kept for extended periods to enable trace-back of product following delivery and intentional commingling.

Canada has a long history of mustard research, production, processing and export. Since Canadian farmers began planting mustard in 1936, we have come to dominate global export trade, house one of the industry's most experienced germplasm development and research teams, and boast the most technologically advanced production methods in the world. By all accounts, Canada is the major global exporter of mustard as a commodity.

The agronomic characteristics, especially drought tolerance, of the mustard species *Brassica juncea* (Brown or Oriental mustard) and *Sinapis alba* (white or yellow mustard) have established mustard as an important specialty crop in the Canadian prairies. There is also an opportunity for *Brassica carinata* (Ethiopian mustard) for cultivation in Canada to contribute to this sector.

This current study has focused on the development of a market-driven portfolio of ingredients and industrial products that can be manufactured from modern mustard cultivars and elite breeding lines. Mustard processing and manufacturing includes:

- Conventional mustard milling to produce condiments and spice ingredients.
- New concepts of biorefining involving the extraction of mustard grains and isolation, purification and modification of the constituents to yield bulk food, feed, fuel and industrial ingredients with commercial value.

In both cases, the fractions initially extracted are further treated by secondary and tertiary levels of manufacturing before finished products are produced. These derivative products drive the price and extent of processor demand for mustard seed at the farm-gate. All levels of manufacturing - primary, secondary and tertiary – are connected and integral to the value proposition and business case for each product.

The mustard species and genotypes considered in this strategic plan are listed in Table 1.

Table 1: Species of mustard and related industrial uses

Species	Industrial Use
Oriental mustard (*Brassica juncea)*	Condiment Canola quality, high oil content, food or industrial use Industrial oilseed, high oil content, high erucic, high glucosinolate
Ethiopian mustard (*Brassica carinata*)	Condiment Industrial oilseed, high oil content, high erucic, high glucosinolate
Yellow mustard *(Sinapis alba)*	Condiment Industrial oilseed, high oleic, low glucosinolate

1.2 Key Areas of Focus

The primary fractions of economic importance in mustard include:

- Mustard oil, of varying fatty acid composition including erucic acid;
- Mustard meal containing crude protein, crude fibre and minor constituents including glucosinolates;
- Mustard mucilage in the hull, in the case of yellow mustard only;
- Mustard protein isolates and concentrates which can be extracted from the meal; and
- Secondary metabolites present in small amounts but which may have commercially useful biological or chemical significance and are potentially of very high value.

When initially extracted from the grain, these fractions are in a crude form and are often unsaleable. Each fraction typically requires purification and further refining to make them commercially useful products.

To maximize the economic returns from mustard and have a competitive advantage, it is desirable to find high-value uses for all the constituents of the grain. Mustard's primary usage today in North America and Europe is in the food industry where it is utilized as a condiment, filler and meat extender. In India, mustard oil is consumed as a food. However, in North America and Europe, mustard oil is considered inedible due to the high content of erucic acid. **Expanding the industrial utilization of mustard depends upon exploiting the full genetic potential of the crop and on optimizing the use of all the seed components including erucic acid.**

Processing schemes that are different from those now applied by the condiment mustard industry and by canola crushers are considered essential to creating new high-value opportunities from mustard. Research for this strategic plan considered a range of uses for mustard such as:

- Oils for the manufacture of biofuels and oleochemicals (a particular focus was placed on erucic acid);
- Bioactive ingredients as natural health products, functional food ingredients, and biopesticide;
- Protein isolates and concentrates for food and industrial purposes;
- Expanding the current market for mustard in specialty and gourmet products.

Mustard grains are quite diverse in their composition and utility. This diversity leads to an extremely large number of processing alternatives. Processing schemes that are different from those now applied by the condiment mustard industry and by canola crushers are considered essential to creating new high-value opportunities from mustard. The range of processes that can be applied to mustard and the diversity of end products are illustrated in Figure 1.

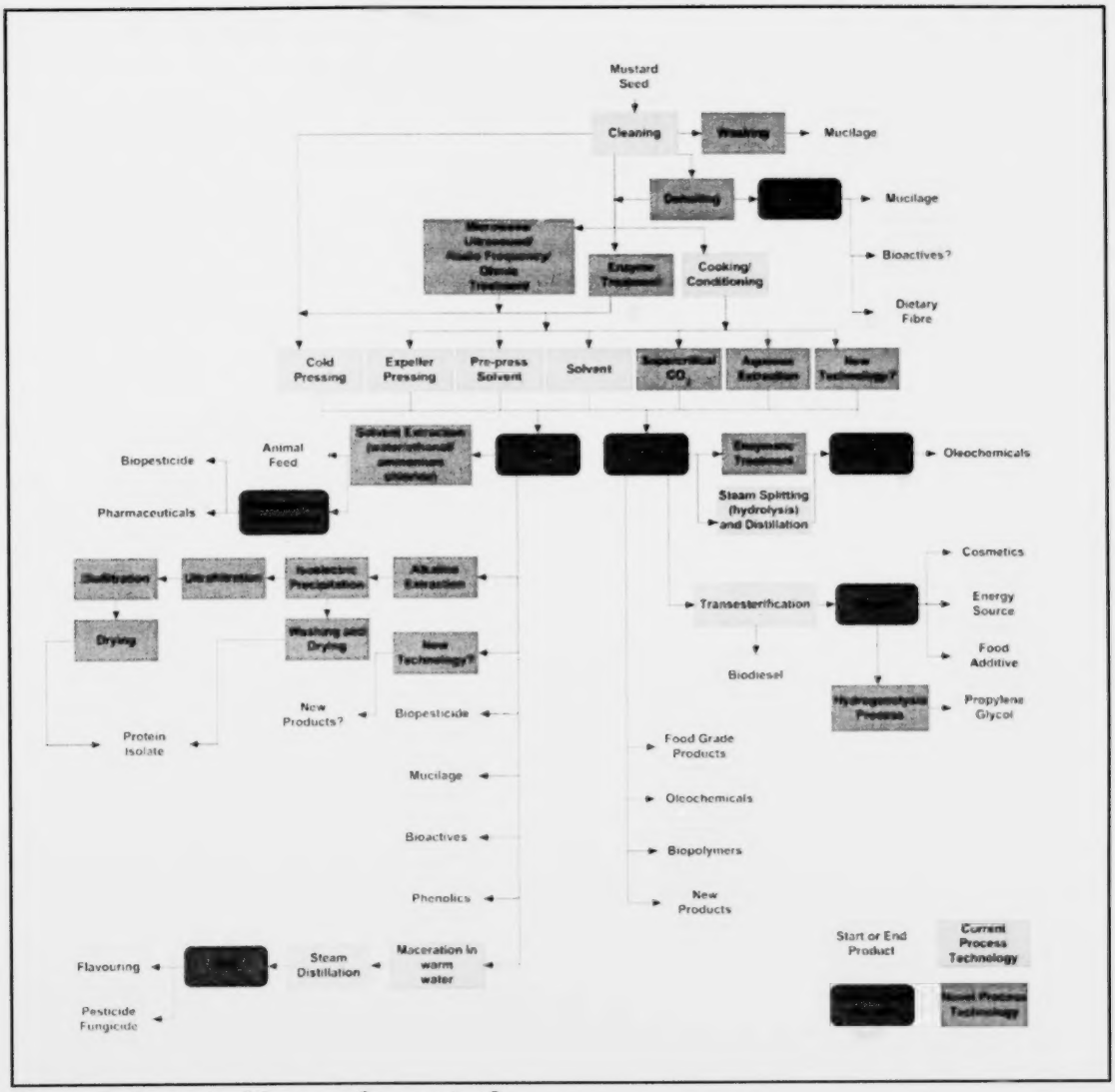

Figure 1: Opportunities map for mustard

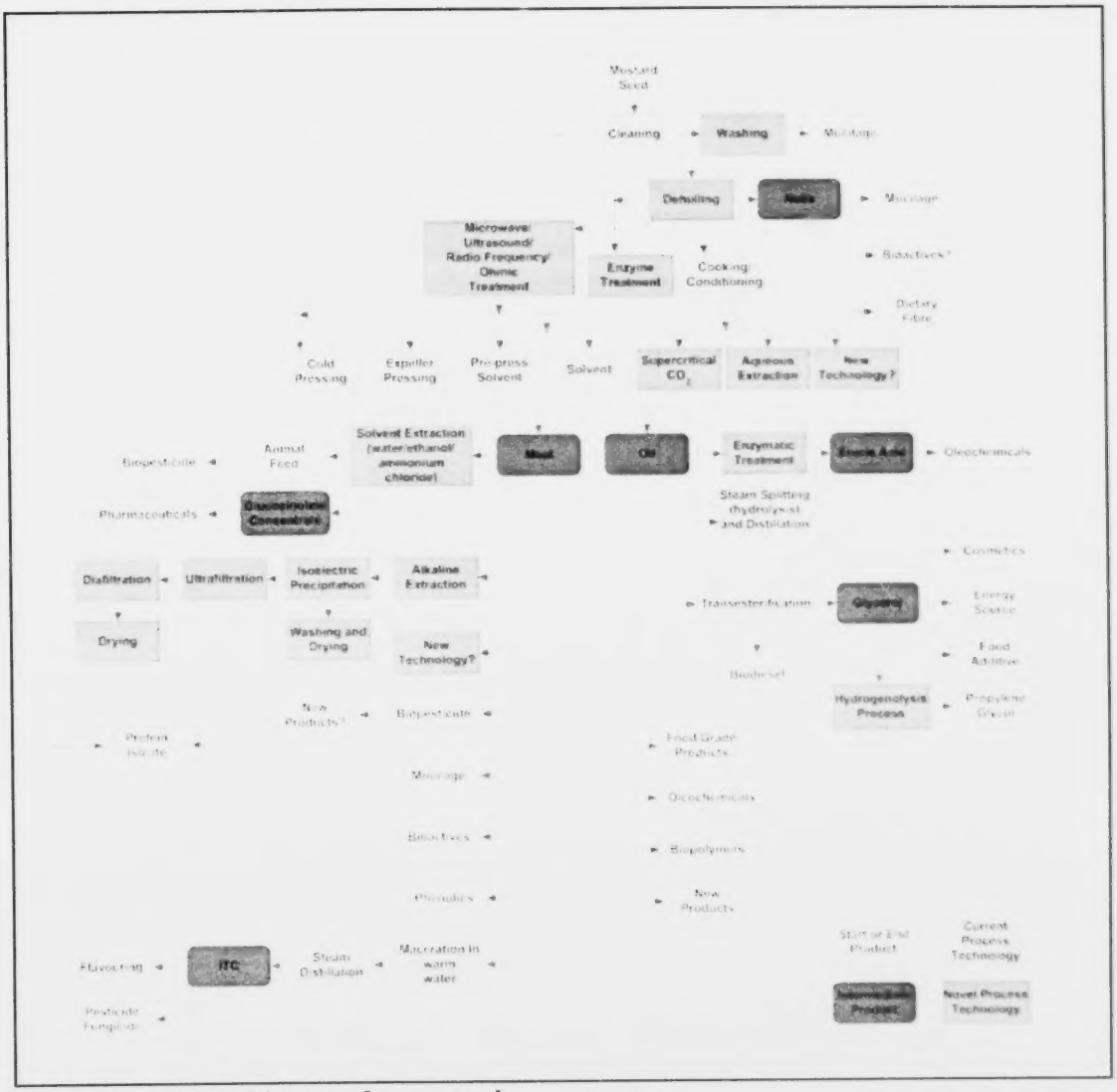

Figure 1: Opportunities map for mustard

As constituents move through their various stages of conversion, the processing schemes become increasingly more specific as to the equipment and operating parameters and are increasingly less flexible to changes in feedstock or product output.

Manufacturing in North America is capital intensive. Economies of scale therefore are particularly important for manufacturing to be profitable. The small scale of the present mustard manufacturing compared to manufacturing involving other crops such as canola, soy and wheat is a significant barrier. Small scale can quickly make many product concepts and manufacturing schemes uneconomic.

The recommendations that follow attempt to bring into sharp focus only those schemes that have a high probability of commercial success through focused investment which addresses strategic gaps in processing technologies and product development.

2. Mustard Opportunity Assessment

2.1 Overview

In this research it quickly became clear that there were a multitude of opportunities that might be explored. To impose some sense of priority, a filter was created through which opportunities were passed. The filter was composed of five criteria:

1. Is the opportunity a primary economic driver for mustard?
2. Is there existing market potential?
3. Is there an opportunity for commercial production within the next ten years?
4. Is it technically feasible within the next ten years?
5. Would the opportunity attract private investment?

The key opportunities that came through this filter were biofuel and biofuel additives, biopesticide, and an integrated mucilage plus protein opportunity. Table 2 summarizes the results of the screening exercise relative to the criteria above.

Table 2: Opportunity assessment and validation criteria for mustard processing alternatives

OPPORTUNITY	CRITERIA				
	Primary economic driver	***Mkt. potential exists***	***Production in 10 yrs***	***Technically feasible***	***Attracts private capital***
Biofuel and biofuel additives *Brassica juncea and carinata*	Biodiesel driver: requires high volume; can complement other oilseeds	Markets exist and continue to grow	Ready now; production capacity exists, need partners for mustard	Technology exists and continues to be refined	Capital is available, growing interest among investors
Biopesticide *Brassica juncea and carinata*	May require high volume, utilizes meal from biofuel	Market need exists, ability to capture value needs testing	Ready two years - mustard crush meal is biopesticide product	Technology exists, scale-up needs to be tested	Some investment capital available, more is needed
Mucilage *Sinapis alba* **Protein** *Sinapis alba, Brassica juncea and carinata*	As oil market grows, creates alternative use for meal (especially low glucosinolate)	Protein market is growing, ability for mustard to capture needs testing	Technology exists, scale-up and efficiency addressed in next six years	Technology exists	May attract private capital if business proposition validated

None of these opportunities are currently commercial. Together they represent the best options available to the mustard industry as it pursues growth and high-value products.

Once the seed profiles, technologies, facilities, product formulations, products, partnerships and retail relationships are created for these products, some of the opportunities screened out of this analysis could be brought forward for further study.

Once the key opportunities are captured, they will likely enable many other follow-on opportunities. For example, a sophisticated player in biofuels manufacturing might find a significant, but secondary, opportunity in oleochemicals such as nylon or plastics.

Plastic from mustard represents an interesting example of what might be enabled once primary processes enable a value-chain for bioindustrial applications with mustard. Plastics, especially ultra-high performance plastics, are a low-volume, high-premium opportunity.

While it may never be feasible to create a freestanding facility dedicated to plastics, plastics as a "bolt-on" opportunity could be significant. Preliminary analysis suggests that economic opportunities from plastics could add close to half the value currently contemplated from biopesticide opportunities.

2.2 Economic Results

Given the need for economically viable primary processes and recognizing the need to create early wins within Mustard 21, the first phase of this analysis has focused on biofuel, biopesticide, mucilage, and protein. As mentioned, a few secondary opportunities in plastics and nylon were also analyzed.

Comparative Analysis

Table 3 presents and compares the results of the economic analysis on a tonnage and 100,000 acres basis for biofuel, biopesticide, mucilage, and protein. The biofuel and biopesticide models were integrated to account for both oil and meal. Mucilage and protein models were integrated in recognition of how complementary these products are when processed together. Both of these models are supported by detailed analysis that includes order of magnitude estimates of capital and operating costs, evolving market dynamics, and future development within technologies and seeds. The results of this work are presented in the specific sections below that discuss each opportunity.

In general, the modeling integrated the use of oil for biofuel with the use of meal for biopesticide from Oriental and Ethiopian mustard. To provide comparative references, the analysis also includes benchmarks for current mustard uses, a benchmark for detoxified meal for feed, and current and future opportunities for canola quality mustard.

The movement from an exclusively condiment-based use of mustard to biofuel and biopesticide use is a strong opportunity. Biofuel is an important driver in this economic model and provides a large volume use of the oil. Using the meal for biopesticide appears to be another significant opportunity, especially relative to a detoxified feed use (four times more valuable) or even the current condiment uses (three times more valuable).

Production of mucilage and protein was integrated for yellow mustard. Relative to current uses of yellow mustard the gain was nearly three times the current value. In future scenarios, where yields in the field and in the protein rise, the gain is more than five times higher.

Relative to current uses of canola, including canola oil for biofuel, mustard has advantages. These are primarily attributed to the high-value uses of meal for biopesticide or protein and use of mustard oil for biofuel production. If further research can show the high erucic content of mustard oil carries higher premiums in oleochemical use, this story becomes even more positive. This is significant as we observe increasing competition for farmland in areas where both mustard and canola type Brassica can be grown.

It is important to note that the comparisons in Table 3 are on a revenue basis; the table describes value added to the seed. The costs of biofuel and biopesticide production are substantial and further investment is required for better seed profiles, more efficient manufacturing technologies, market development and product refinement. These results only suggest the magnitude of opportunity – further work with an industrial partner is needed to analyze specific business opportunities available to individual producer groups.

Table 3: Mustard opportunities table (per tonne and per 100,000 acres)

Current and Future Opportunities	Existing Brassica Crops in Western Canada					Mustard Opportunities						
Parameter	Canola B. napus Benchmark	Canola B. juncea Benchmark	High Erucic Acid Rapeseed	Condiment B. juncea	Condiment Sinapis alba	Canola B. juncea	Brassica Juncea / Carinata	Brassica Juncea / Carinata	Brassica Juncea / Carinata	Brassica Juncea / Carinata	Sinapis alba	Sinapis alba 0,0
Market Factor						add 5% oil	current profile	add 15% oil, 60% C22:1	current profile	add 15% oil, 60% C22:1	current profile	low gluc, >80% oleic
Use of Oil in Seed	Food or Renewable Fuel	Food or Renewable Fuel	HEAR Oil	Condiment	Condiment	Food or Renewable Fuel	Renewable Fuel	Industrial Oil	Renewable Fuel	Industrial Oil	Industrial Oil	Industrial Oil
Oil content in seed	43%	41%	46%	32%	28%	47%	32%	47%	32%	47%	28%	35%
Fatty acid, C20:1 (gadeolic acid)	1.4%	1.4%	1.4%	13.0%	11%	1.40%	13%	13%	13%	13%	11%	11%
Fatty acid, C22:1 (erucic acid)	0.2%	< 2%	45.0%	28.0%	36%	< 2%	28%	60%	22%	60%	36%	< 2%
Solid component in seed	Feed meal	Feed meal	Feed meal	Mustard flour	Mustard flour	Feed meal	Bio-pesticide	Bio-pesticide	Feed meal	Feed meal	Proteins & Extracts	Proteins & Extracts
Glucosinolate, genetic determined	low gluc.	low gluc.	low gluc.	high gluc.	high gluc.	low gluc.	high gluc.	high gluc.	high gluc.	high gluc.	high gluc.	low gluc.
Glucosinolate - low, process determined	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	detox	detox	N/A	N/A
Germ Plasm Status	commercial	commercial	commercial	commercial	commercial	future	commercial	future	future	future	commercial	future
Yield (MT/ha)	1.4	1.1	1.1	0.9	0.7	1.4	0.9	1.35	0.9	1.35	0.7	1.2
Revenue/MT seed ($Cdn)	$625	$608	$749	$950	$1,000	$861	$2,688	$2,981	$608	$1,587	$2,865	$3,138
Revenue /100,000 acres (Millions $Cdn)	$35	$27	$33	$35	$28	$49	$98	$163	$22	$87	$81	$153

As mentioned earlier, plastic and nylon opportunities were also analyzed within this project. The volume of mustard used within the model is not comparable to the amount used in the models for biofuels, biopesticide or protein. There is, however, significant economic potential, especially for ultra-high performance plastics such as Kevlar.

Based on a premium product such as Kevlar, the volume of mustard as an input would be very low (less than 700 tonnes). However the marginal value added to the mustard oil is extremely large (more than 200 times higher than biofuel use). If mustard production and manufacturing are to grow in Canada, a high-volume use like biofuel is needed to encourage subsequent development of high-value oleochemical manufacturing.

Sensitivity Analysis

The results of this economic analysis were tested for sensitivity and robustness using Palisade's @RISK Monte Carlo simulation. Variability was introduced to key variables and 10,000 scenarios were run to measure the upper and lower bound of the results given expected volatility in key drivers such a seed price, product price, conversion ratios, and market capture rates.

The results are most sensitive to changes in product prices, biopesticide application rates, and conversion ratios for protein and mucilage. The reported net present values are reasonably robust with the biopesticide results standing a five percent risk of being less than $325 million. The protein results have a five percent risk of being less that $250 million.

The sensitive analysis suggests that potential areas for future work might include: validating product prices and formulations through pilot-scale projects, breeding seed profiles to enhance yields of oil and protein, and exploring strategies to detach the price of industrial mustard from mustard for food-based uses.

3. Mustard Strategy for Opportunity Sectors

3.1 Biofuels and Fuel Additives

3.1.1 Renewable Fuels and Fuel Additives Product Overview

Potential uses of mustard for industrial purposes are illustrated in Figure 2.

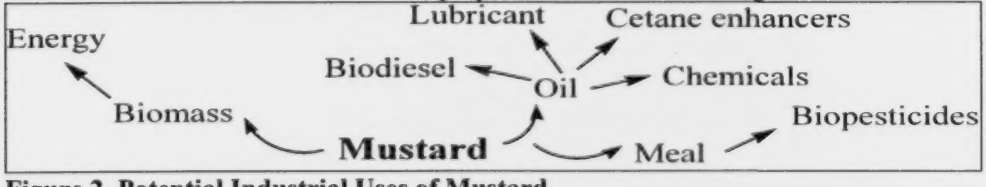

Figure 2. Potential Industrial Uses of Mustard

The Government of Canada is presently considering introducing a Renewable Fuel Standard that will mandate 2 percent and 5 percent renewable middle distillate fuel blends with diesel by 2010 and 2013 respectively. At these levels, there will be demand

for 500 and 1300 million liters respectively of renewable middle distillate fuel per year. There also appears to be long-term potential for Canada to export significant quantities of canola and canola biodiesel to Europe and USA.

Canola oil from *Brassica napus* and *Brassica juncea* is the oilseed most available in Canada for biofuel production. Canola quality *B. juncea* mustard could be an immediate crop alternative available to mustard growers for biodiesel production in semiarid areas of Western Canada. Canola Council of Canada's demand projections for canola oil for food and fuel use suggest an opportunity of 1 – 2 million acres annually for mustard production. This represents a $450 – $900 million opportunity in crop production for mustard growers.

Mustard oils can be utilized to manufacture two types of renewable middle distillate fuels:

- Biodiesel - fatty acid methyl esters (FAME) similar to those manufactured from canola, soybean and palm oil and also animal fats.
- Green diesel - liquid hydrocarbons produced by hydrotreating vegetable oils either as neat oils in dedicated hydrotreating units or as blends of vegetable oils and petroleum feedstocks with a petroleum refinery.

A key barrier for petroleum refineries considering green diesel and the use of vegetable oils to make green diesel is the large size of the petroleum refineries compared to the available quantities of vegetable oils. Petroleum refiners are unwilling to interrupt their world-scale processes for small quantities of vegetable feedstocks. If green diesel is to be commercialized, it seems this will occur only in small dedicated hydrotreating facilities which, by the scale of the typical biodiesel plants, will still be extremely large.

Biodiesel production from mustard is anticipated to follow a similar path to biodiesel from canola or soybeans. An important differentiator may be the high erucic acid in mustard. From the literature it seems possible that high erucic mustard FAME might:

- Lower the cloud point and pour point of blended fuels more than FAME from canola, soybean, peanut or used vegetable oils.
- Have a lower incidence of precipitates above the theoretical cloud point of blended fuels.

If true, these features could open up important market niches for mustard FAME.

Economic Analysis

Using an integrated economic model (which included biopesticide or detoxified feed from meal), oil for biofuel contributed 12 percent of the revenue ($300/tonne). As new seed profiles become available, especially those with high oil contents or greater concentrations of erucic acid, this contribution could rise to 40 percent – a gain of more than $600/tonne in additional revenue.

An important constraint to the development of a biofuel based on mustard is that the summer and winter operability of mustard FAME having either low or high erucic acid contents is not known. Precipitates have been observed coming out of diesel / biodiesel blends at temperatures above the theoretical cloud point of the blended fuel. These precipitates have accumulated in fuel storage tanks and plugged fuel dispenser filters. The ASTM Petroleum and Lubricants Committee has formed a task force to understand this problem.

3.1.2 M21 Strategy for Renewable Fuels and Fuel Additives from Mustard

High oil, high glucosinolate cultivars of *B. juncea* are available; work is progressing to cross these lines and produce optimal cultivars for the biodiesel industry. It is recommended this work continue as *B. juncea* has excellent blackleg resistance and drought tolerance. The seed yield and oil content of the breeding lines are excellent. Combined with the potential for value-added co-product development of a biopesticide meal, it is apparent *B. juncea* could make a significant contribution to the biodiesel industry in both the short- and the long term.

Strategic action plan:

Product development and commercialization in two key genotypes to realize the manufacturing opportunity for mustard in the renewable middle distillate fuel market:

1. **Industrial *B. juncea***
    a. Development of high yield, high oil, high glucosinolate cultivars.
    b. Critical characterization and fleet testing of the high erucic mustard FAME, particularly for storability and winter operability.
    c. Development of commercial uses for the mustard meal as a biopesticide soil amendment or detoxified feed supplement.
2. Canola quality *B. juncea*
    a. Development of higher yielding, higher oil content cultivars.
    b. Critical characterization and fleet testing of low erucic mustard FAME particularly for storability and summer operability.

3.2 Biopesticide

3.2.1 Product Overview

Mustards produce glucosinolates. Glucosinolates are biologically active compounds with biocidal and pesticidal qualities. The global pesticide market is a multi million dollar market predicted to increase 1.7 percent per year to $US 28.4 billion by 2009. While soil fumigants are a relatively small component of this large pesticide business, the fumigant market is a high-value market. Mustard meal as a natural biopesticide represents a large opportunity for growth in Canada.

The control of nematodes, diseases and insects in professional turf, golf courses and specialty high-value crops will need significant volumes of mustard meal. The present fumigant market potential in the specialty high-value crop and fruit market that can be

treated by conventional fumigants is approximately 8.3 million acres. There is also the additional, higher value professional turf and golf course market. The estimated market for these two sectors is between $400 and $600 million.

Mustard meal and/or AITC as a natural bio-fumigant have significant advantages including:

- Natural and renewable product;
- Ease of use with no need for special application equipment;
- No restrictions, e.g. to be applied only by a certified applicator or a 24 hour reentry;
- Fertilizer value; and
- Soil amendment properties.

The natural biopesticide market is expected to grow with consumer preference for natural products over synthetic chemicals. Additionally, conventional synthetic products are increasingly restricted in use or, in some cases, even being removed from the market due to unacceptable environmental and health risks or concerns.

Economic Analysis

In the analysis, biopesticide was modeled together with biofuel. Where seed contained less than optimal levels of glucosinolates, it was assumed to enter a detoxified feed meal market. Biopesticide contributed about 65 percent of total revenue or $2,400/tonne with another 20 percent coming from detoxified seed. The production model broke even after four years with a significant net present value of $400 million over ten years.

Issues that may compromise this promising market include the long-term security of supply, consistent quality, high use rate, freight costs, and the competing price and farm gate return of condiment mustard as competition. This is a high-risk opportunity for the following reasons:

1. The lack of regulatory approval of mustard meal or AITC as a pesticide for turf.
2. There is a need to demonstrate the robustness of product performance on a large scale and across various regimes to gain market share.
3. There is a need to establish a sales and distribution channel for delivery of product to the customer.
4. The lack of commercial manufacturing facility to deliver a quality and quantity of product to meet the market demand.
5. Validation of market potential, realistic market share and price elasticity for the product.

For M21 to deliver on its long-term objective of a $500 million economic impact, there has to be at least two new large market opportunities. Mustard as a biopesticide for the control of nematodes, diseases and insects in professional turf and on golf courses can be one of those opportunities.

3.2.2 M21 Strategy for Biopesticide from Mustard

It is recommended that M21 assume leadership to champion the coordination and promotion of the opportunity for *B. juncea* as a natural biopesticide as one of its top priorities. Successful delivery of this potential will require large volumes of mustard seed, new infrastructure and market development. Strategically focused investment in this product channel will help M21 accomplish its goal of creating significant economic value in the prairies.

Strategic action plan:

1. M21 to assist in the completion of an in-depth analysis of the opportunity by defining market potential and the economic feasibility of the business.
2. Support work to obtain regulatory approval in the USA and Canada.
3. Help establish appropriate industry infrastructure in Saskatchewan through end use market.
4. Invest resources to coordinate a long-term breeding program to develop *B. juncea* and *B. carinata* with enhanced AITC content to support the biopesticide market.
5. Develop processing technology for production of *B. juncea* meal with highest levels of glucosinolates. Technology is needed to ensure that the glucosinolate fraction is preserved, at least through the first expelling of the seed.
6. Develop a market for the mustard seed with low glucosinolates not suitable for biopesticide or condiment use. Modifications to the process to detoxify the meal for use in feed supplements would be highly beneficial. This could be achieved in several places within the process, but most likely after the seed is flaked.

3.3 Condiments and Spices

3.3.1 Condiment Product Overview

Mustard has long been used as a spice in the condiment trade. More recently, mustard has seen increasing popularity as an ingredient in many food service items including appetizers and entrees. As diners' interest in experimenting with new flavours is at an all-time high, the timing is perfect for promoting mustard as a flavorful, low fat and natural ingredient for many foods.

Several macro trends which have particular significance for product development in mustard are affecting the 'traditional" food service industries including: globalization, ethnic diversity, growth in international cuisine, and interest in authentic flavors and spicy foods. Mustard use appears also to be in resurgence due to the consumer's desire for foods that are low-fat and full flavour. Organic is becoming a growth segment for condiments that consumers also link to gourmet and better taste.

Given the many spices, ingredients, techniques and menu ideas that are emerging, mustard is very well positioned to be a key ingredient in these culinary approaches.

3.3.2 M21 Strategy for Mustard Condiment Market Development

It is recommended that M21 assume leadership to promote the health advantages and culinary characteristics of traditional condiment mustard and capitalize on increased consumer interest in products which are all natural, organic, low carbohydrate, lower fat and flavorful. Successful delivery of this objective will: support the growth and development of the current mustard industry; create consumer and market pull for new types of specialty and boutique mustard products; and lead to the creation of economic value in the Prairies. This will be an incremental opportunity for the present condiment business.

Strategic action plan:

1. M21 working in partnership with Agriculture and Agri-food Canada in the development and delivery of the Mustard component in AAFC's "Branding Canada" strategy.
2. Develop promotional materials that promote the health advantages and culinary characteristics of traditional condiment mustard. Profile Canadian mustard at trade shows and international culinary events.
3. Invest in product development focused on gourmet and specialty applications in order to expand product offerings for mustard based condiments and food uses of deheated mustard flour.

3.4 Protein and Food Ingredients

3.4.1 Mustard Protein Isolates and Concentrates

Global sales of protein ingredients are expected to increase to $18 billion by 2010. Europe is currently the largest market for protein ingredients, with sales expected to reach $10 billion by 2010. The USA is the fastest growing market, with a predicted annual growth rate of 7.6 percent.

The plant protein ingredients market is the fastest growing protein segment, with a projected annual growth rate of 8.0 per cent over the next five years. Ready meals and the emergence of markets such as sport nutrition and dietary supplements propel the demand for new sources of proteins. Soy proteins are the major competitor for new plant based protein sources and dominate the market.

Plant proteins are increasingly being used in gluten-free products. The USA market for gluten-free foods and beverages is currently estimated at US$696 million and is anticipated to grow to US$1.7 billion by 2010. Since 2001, the market for gluten-free products has grown at a compound annual rate of 27 percent and is anticipated to grow 25 percent per year until the year 2010. This market segment represents an opportunity for new plant-based proteins.

Since mustard is used mainly in the condiment trade, it has received little attention as a protein supplement for animal feed and almost none for human health. Deheated and defatted mustard products are currently marketed into the food industry mostly as fillers.

Thus, there appear to be opportunities to expand mustard protein usage in traditional foods and for new products aimed at the health and nutrition market.

The protein currently available in other oilseeds, such as canola, is deeply discounted because of damage to the protein during oil extraction and the high crude fibre content of the resulting mid-protein meal. This has encouraged several firms and research groups to invest in R&D to develop new processes which:

- Minimize protein damage during desolventization and solvent recovery;
- Provide an alternative solvent to hexane now used exclusively in oil extraction;
- Dehull canola and mustard seed to produce a higher protein content meal; and
- Fractionate or extract the mid-protein meals to produce higher value protein isolates and concentrates free of the low value, high crude fibre fraction.

Generally speaking, technical advances in the extraction of protein from canola and the development of canola protein isolates and concentrates will be applicable to oriental mustard and yellow mustard. Research suggests the processing costs will decrease and product quality and functionality increase in the order of 1) *Sinapis alba* yellow mustard, 2) *B. juncea* oriental mustard and 3) *B. napus* canola.

The development of mustard protein concentrates and isolates with unique and/or improved functional properties has only received minor attention from researchers. Because of the abundance and techno-functionalities, there may be potential to develop plant protein ingredients from mucilage and defatted yellow mustard meal.

Economic Analysis

In the analysis, current profiles for yellow mustard were used to develop a mucilage and protein based model. Oil was assumed to enter biofuel markets. Protein isolates and protein concentrates contributed $1,800 per tonne with oil contributing just over $400/tonne. Improvements in protein content, oil content, and yields in the field may add an additional $100/tonne. The economic model broke even in three years with a positive and significant net present value of $400 million over ten years.

Allergenic proteins will be the main constraint for the development of mustard protein isolates or concentrates. The European Union includes mustard on its list of priority allergens which must be declared when present in foods. Research continues to find means to remove or reduce allergens in soy. The success of the allergen research in soy has improved the competitiveness and commercialization of soy for use in foods. The development of similar technologies would be necessary for mustard proteins.

Obtaining regulatory approvals for mustard protein ingredients will require significant research and resources. Given the number of constraints described, the feasibility of mustard protein competing in this market will need to be assessed.

3.4.2 Mustard as a Food Preservative

Mustard contains significant amounts of glucosinolates which are precursors of flavour components and therefore desirable when mustard is used as a condiment. These same glucosinolates have been documented to have antimicrobial and antifungal properties. Used in the vapor phase, glucosinolate derivatives (AIT) have been shown to be a potent antifungal agent when included in modified atmosphere packaging of food products. This is important as the use of natural rather than synthetic antioxidants has gained popularity.

AITC has GRAS (Generally Recognized as Safe) status in the USA as a food flavoring and food preservative in packaged foods. Thus regulations should not be an impediment. Studies have shown that the addition of low-pungency ground mustard seed may be as effective as synthetic additives in controlling rancidity in ground pork. Evidence supports the effectiveness of isothiocyanins including AIT as inhibitors of several plant pathogens.

A limitation in the development of mustard protein is the presence of anti-nutritional constituents such as glucosinolates, phytates, and phenolics. The removal of these constituents must be a primary consideration (over the short term through processing and long term through plant breeding) in the development of mustard protein for food applications.

In the long term, selection for low-allergenic lines free of glucosinolates and phytates needs to be undertaken. Obtaining Novel Foods status in Canada and GRAS (Generally Recognized as Safe) status in the US is necessary before mustard protein will be allowed in foods.

3.4.3 M21 Strategy for Mustard as a Source of Protein and Food Ingredients

It is recommended that M21 develop a research strategy to capitalize on this opportunity including securing support (cash and/or in-kind) from industry and other funding organizations.

Strategic action plan:

1. Investigate *in vitro* antimicrobial activities of AIT and other glucosinolate breakdown products on the most frequently encountered and problematic bacteria and fungi found in prepared foods and fresh-cut produce;
2. Develop a strategy for applications in the above-mentioned food products including ensuring that regulatory requirements are met for new mustard-based natural preservatives.
3. M21 to conduct an assessment as to how current mustard processing technologies affect the allergenic potential and/or allergenic proteins. A competitive and economic analysis including competing protein sources, current processing and future technology requirements for yellow mustard protein must be undertaken.
4. Invest to achieve significant economic improvements in near-to-commercial technologies for mustard protein extraction and explore the adaptation of existing processes under development for canola and other crops.

5. Address the process design challenge to economically integrate oil-extraction techniques with the best of the protein extraction technologies.
6. Investigate protein functionality for food and high-end feed applications.
7. M21 to oversee research aimed at the removal of anti-nutritional constituents through processing and, in the longer term, through plant breeding (i.e. selection for low-allergenic lines free of glucosinolates and phytates).
8. Determine the feasibility, resources and timing required to obtain Novel Foods status in Canada and GRAS (Generally Recognized as Safe) status in the USA for mustard protein for food use.

3.5 Mucilage and Fibre Ingredients

3.5.1 Overview

Mustard seed from *Sinapis alba* is an excellent source of soluble fibre, primarily found as mucilage and beta-glucan. Additionally, because of their viscous nature, mustard gums from mucilage have potential applications as food and supplement ingredients for serum lipid lowering and blood glucose moderation. The gel-forming characteristics of these gums can trap lipid and glucose. Due to these properties, there is interest in determining the effects of isolated mustard gums on the glycemic index (GI) which is an indication of how rapidly carbohydrates are digested.

Low-glycemic products target the over 20 million diabetics in the USA in addition to consumers concerned about boosting their energy level and losing weight.
There is strong scientific evidence that supports low GI diets with weight loss as well as diabetic control. This has prompted support from both the Canadian Diabetes Association and the American Diabetes Association.

In early work in humans, incorporating mustard fibre into white bread had a modest but significant effect in reducing the GI of the bread. A significant reduction in percent peak rise in postprandial blood glucose was also observed in both normal and diabetic human volunteers. Of interest, *Brassica juncea* seeds are used by diabetics in India to control blood glucose levels.

Economic Analysis

In the analysis, mucilage and protein production were integrated. Mucilage contributed $600 per tonne (around 20 percent of total revenue). As stated earlier, the economic model broke even in three years with a positive net present value of $400 million over ten years.

3.5.2 M21 Strategy for Mucilage and Fibre Ingredients

Following completion of the animal research, M21 will need to determine if further animal work followed by confirmation of these effects in humans will be required. Should mustard mucilage be as effective in diabetic conditions as other soluble fibres (such as oat and barley beta glucan), the opportunities in products for both prevention and treatment of diabetes are significant as are applications for weight loss products.

Processing research to determine economical and feasible scale-up technologies for the manufacturing of mustard fibres would be considered.

Strategic action plan:

1. Define and freeze the best process design for mucilage processing for the next 3 years to validate technical feasibility of the design and produce sufficient quantities of mustard mucilage for customer product formulation and regulatory trials to establish the product's health benefits.
2. M21 support for further animal research and evaluate the resource requirements for human clinical trials.
3. Characterize the antioxidants of mustards to establish their commercial potential. Antioxidants from canola are being investigated widely for new extraction processes and higher yield of active compounds.

3.6 Oleochemicals

3.6.1 Oleochemical Product Overview

Natural oils and fats that are important as food ingredients are also renewable feedstock for the oleochemical industry. Eighty percent of the world's fats and oils are derived from plants with the rest coming from animals (with microbes representing a fraction of one percent). Eighty percent of fats and oils are used for food, six percent goes to feed, and oleochemical production consumes 14 percent or 17 million tonnes per year.

The oleochemical industry converts oils and fats into industrial chemicals. Oleochemical products are typically biodegradable and do not contribute to a net increase in the amount of CO_2 in the atmosphere or to the acidification of soil and water. Feedstock for oleochemicals is often supplied as byproducts from the food industry that are not suitable for human consumption.

Mustard varieties with high oil content are of particular interest as a renewable feedstock to the oleochemical industry. Erucic acid constitutes a large proportion of the total fatty acid content in Brown and Oriental varieties. High erucic oils are often used as lubricants. They can also be processed to form other materials such as polymers and surfactants. Oils high in oleic acid also have valuable oleochemical and food uses.

Oleochemical products find applications as lubricants, liquid fuels, paints, surfactants, detergents, soaps and cosmetics. More than 90 percent of all oleochemical reactions with triglycerides are carried out at the ester bonds. However, transformations by reaction of the carbon–carbon double bonds, such as epoxidation, ozonolysis, dimerization and oleofin metathesis are becoming increasingly important industrially.

Olefin metathesis is a catalytic reaction of the carbon–carbon double bond in which the olefins are converted into new products. It is a well-established process in the petrochemical industry and its potential for the oleochemical industry has been recently demonstrated.

Erucic acid can be converted to a number of derivatives such as behenic acid, erucate esters, erucamide, erucyl alcohol, and brassylic acid. Erucamide is used as an antiblock and slip-forming agent for the production and functioning of extruded polyethylene and propylene films. Erucyl alcohol is used in producing brassylic acid which can be used to manufacture nylon 13, and pelargonic acid, a nine-carbon diacid.

Economic Analysis

Economic analysis of oleochemical opportunities is investigated by modeling nylon and plastic production from mustard. Results suggest that production of nylon and even higher valued performance plastics is unlikely to be economically viable at present. The published production methods are high cost, market premiums are too low, and existing markets are highly competitive.

Ultra-high performance plastics like Kevlar, however, appear to have strong technical and economic drivers. These products are more narrowly defined, have higher premiums, and broader opportunities for valuable by-products including using the remaining oil constituents for biofuel production. The ultra-high performance plastic scenario, assuming certain technological advances, broke even immediately and grew to a net present value of $280 million over ten years.

3.6.2 M21 Strategy for Oleochemical Derived from Mustard

Mustard oil will compete with HEAR and soy oil in industrial applications but its functionality and utility must be clearly demonstrated. Research priorities in the oleochemical area can be categorized as short-, medium- and long-term with time horizons of 2-3 years, 5-7 years and 10-12 years respectively. These time estimates assume that the research in each category is vigorously initiated immediately.

Strategic action plan:

1. Short-term outcome – determine the physical, chemical and engineering properties of the oil, extractable oil fatty acid fractions and derived chemical feedstocks. The applications at pilot and full plant scale must be demonstrated in parallel with a major marketing effort in order to establish mustard as a viable alternative to other North American plant oils.
2. Medium-term outcome - pursue two major goals in the oleochemical area:
    a. Develop novel or improved technology for recovering and purifying fatty acids. Membrane technologies, supercritical processes and absorption technologies - alone and in combination - promise to produce high quality fuel and oleochemical feedstocks.
    b. Develop novel uses for erucic acid and its diacid derivatives, brassylic acid and pelargonic acid. This will include novel applications for engineered polymers such as nylon 13.
3. Long-term outcome - The success of these applications will be greatly enhanced by the development of high oil content varieties containing very high levels of

erucic acid. This will make the purification of erucic acid simpler and the yield higher. This will allow the price of erucic acid and its derivatives to be substantially reduced, resulting in increased demand by polymer and chemical producers.

4. Mustard 21 Priorities

The priority recommendations included in this strategic report come in four categories: plant breeding and agronomy, processing and gross manufacturing, formulation and product development and, finally, market access and partnering.

4.1 Priorities for Plant Breeding and Agronomy

The majority of the mustard is grown in the drier areas of prairies. The drought tolerant trait has been the main reason for its success in the arid areas. **The most significant factor inhibiting a further increase in the volume of mustard production is yield**.

Mustard yield has not kept up with the yield increases of other crops, especially canola, over the last fifteen years. AAFC has the only major mustard breeding program in Canada and has developed a hybrid system for *B. juncea* that can give the initial yield boost (see Table 4). Further refinements will take about five years.

Table 4: Composition Specifications for Breeding Mustard Cultivars by 2018

Species	*B. juncea**		*B. juncea 00**		*B. carinata**		*S. alba**		*B. napus**	
Timeline	Now	2018	Now	2018	Now	2018	Now	2018	Now	2018
Y Mt/Ha	0.9	1.35	1.1	1.5	0.9	1.5	0.7	1.2	1.4	1.7
% Oil	35-39	>50	42-44	>50	24-36	>50	24-32	30-38	44-48	47-50
% Erucic	28	66	0	0	0	66	37-55	0-66	0	0
% Protein	45-49	40-42	46	44	40-44	40-42	47-49	44-48	44-45	40-42
%Mucilage	N/A	N/A	N/A	N/A	N/A	N/A	37-50	50+	N/A	N/A
% AITC	135	2X	0	0	120	2X	N/A	N/A	0	0

* Dry Belt region average yield Mt/Ha

Mucilage - cS*ml/g (viscosity measurement and reported as centistoke (cS) ml/g.

The key requirements for biofuel, biofuel additives, biopesticide and oleochemical production are to increase in the mustard seed:

1. Percentage oil above 50 percent (dry basis) in *B. juncea* or *B. carinata*,
2. Erucic acid content to at least 66 percent in *B. juncea* or *B. carinata*,
3. AITC content *in B. juncea* and *B. carinata* above 2.5 percent,
4. Protein in mustards, and
5. Mucilage in *S. alba*

Weeds, especially hard to control broadleaf weeds, have a direct impact on the mustard crop yield. There are no good selective chemicals to manage weeds like wild buckwheat, Canada thistle, kochia and common mustards. This will be an area that needs to be addressed to keep the growers interested in growing mustard.

The opportunity to genetically modify canola and soybeans was critical to developing the HTC and modifying the oil profile. Genetic modification (GM) of mustard may be the only alternative to obtain the change in oil profile and increase in oil yield necessary for industrial applications. To open up the opportunity for GM, mustard must be unlocked from a food-based production system. **Serious consideration needs to be given to developing an "industrial mustard" that will allow the use of the latest technology like GM within a breeding program.**

4.2 Priorities for Processing and Gross Manufacturing

Biorefining is a term often used to describe total utilization of feedstocks. In this case it would mean utilizing every valuable attribute of the mustard seed. This is particularly important in an environment where the costs of feedstocks as well as production technology are both rising dramatically. If the mustard industry wishes to create additional value from mustard, it must, at every opportunity, subject the constituents initially extracted from the seed to further treating by secondary and tertiary levels of manufacturing before finished products are produced.

Secondary and tertiary levels of manufacturing can occur in or outside the firms and factories performing the initial primary extractions. Regardless, all levels of manufacturing – primary, secondary and tertiary – must be connected and are integral to the value proposition and business case for each product.

Private R&D firms and research groups need support in their efforts to develop and commercialize processes to produce new technical products such as biofuels, biopesticide meal from high glucosinolate oriental mustard, and protein from yellow mustard coupled with biofuel production. Successful delivery of these opportunities will require focused research and coordinated investment by private and public capital towards variety development, process development, product development and commercialization.

4.3 Priorities for Formulation and Product Development

Finding feedstocks and completing production of ingredients is only half the commercialization challenge. Product development and market entry are also critical.

As the mustard industry contemplates the production of ingredients – biofuels, biopesticide, protein, or oleochemicals – it must build capacity to interface with the products its ingredients help formulate. Beyond becoming technically savvy in processing, the mustard industry must become sufficiently proficient in product development. This is an area that should be explored in great detail throughout following phases.

As processors strive for greater integration and higher utilization of inputs, many new opportunities will be revealed by the buyers of their ingredients. If the mustard industry could develop the capacity and relationships needed to dig deeply into the needs of product developers, it will find many more opportunities to increase the value of this industry.

4.4 Priorities for Market Access and Partnering

Market access goes beyond the issues of regulatory approval and GRAS status (though both are critically important). Market access also involves partnering or integrating with other commercial players to reduce risk, decrease transaction costs, and increase the stability of supply and production.

A key success factor for the mustard industry will be the ability of its entrepreneurs and SMEs to interact with those focused on other crops (such as canola) as well as large multinational companies that utilize a broad range of ingredients to produce a wide range of products.

Cooperation with those focused on other oilseeds will be important for taking advantage of the enormous biofuel opportunity within which each crop will play its own unique role. Partnering with other ingredient suppliers will be key to delivering the potential within the oleochemical opportunities described in this report.

5. Mustard 21 Path Forward

Mustard, in the next decade, has the potential to create significant new economic activity through processing of mustard seed in Canada. It is an opportunity that will help mustard to be recognized beyond its traditional condiment segment. The processing of seed in Canada and extraction of value components like oil, meal as biopesticide, mucilage and protein, offer new wealth creation options. In order to capture these opportunities it is recommended that SMDC take LEADERSHIP to be the Champion:

1. M21 strategy – promote to all stakeholders. SMDC must get support for the M21 strategy from the federal and provincial agriculture departments by July 2008. It is critical to align public resources for the long-term development of the strategy.
2. "Industrial Mustard" platform – develop to capitalize on the opportunities.
3. Industry Partnership – establish formal linkage with key partners for each of these opportunities. SMDC will help leverage partners' investments to build the infrastructure for commercializing products.
4. Research Partnership – to address the highest priorities that will help industry partners realize their commercial aspirations. Create a "one stop" for the research providers to decrease the administration burden and help them focus on the task on hand.
5. Resource – develop a long-term resource plan for supporting these priorities to deliver the ambitious vision Mustard 21.

SMDC Board should take on these activities and the accountability as a part of its overall strategic plan.

6. Appendix

M21 technical reports plus additional references not cited with this report, but cited in the strategic plan:

A – Economic assessment report
B – Biorefinery report
C – Biofuel report
D – Biopesticide report
E – Oleochemical report
F – Food & Health report